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Effects of urbanization on meteorological parameters[†]

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सार – भारत जैसे विकासशील देशों में दूसरे स्थानों से आकर बसे लोगों, बढ़ी हुई आबादी के कारण ऊर्जा की खपत में हुई वृद्धि, बढ़े हुए यातायात एवं औद्योगिक कार्यकलापों वनों की कटाई तथा वायुमंडल एवंज जल मंडल में छोड़े गए अपशिष्ट पदार्थों के परिणामस्वरूप शहरों के पर्यावरण पर निरंतर प्रतिकूल प्रभाव पड़ रहा है। शहरीकरण के साथ ही साथ औद्योगिकीकरण की गतिविधियाँ, वर्षा, पवन सापेक्षिक आर्द्रता और तेज़ धूप के घटों जैसे शहर की जलवायु के घटकों को प्रभावित करती हैं। इस शोध–पत्र का अधिकाँश अध्ययन मुख्यतः मध्य अक्षांशीय महानगरों के संबंध में है। निम्न अक्षांशीय महानगरों में शहरीकरण के परिणामस्वरूप आए परिवर्तनों (तापमान को छोड़कर) के विषय में बहुत ही कम जानकारी इस शोधपत्र में दी गई है।

1950 के बाद महानगरों में उद्योगों की संख्या में काफी वृद्धि हुई है। इस अध्ययन के लिए दस लाख़ से अधिक की आबादी वाले पंद्रह शहरों (चार महानगरों सहित) को चुना गया है। पृथ्वी पर आने वाले सौर विकिरण, तेज़ घूप के घंटे, सापेक्षिक आर्द्रता, वर्षा, पवनगति, कुल मेघ आच्छादन और अधिकतम एवं न्यूनतम तापमान जैसे विभिन्न मौसम वैज्ञानिक प्राचलों के जलवायविक आँकड़ों का विश्लेषण रैखिकीय विश्लेषण प्रवृति के आधार पर किया गया है। इन मौसम वैज्ञानिक प्राचलों में पाई गई प्रवृतियों का इस शोध–पत्र में विवेचन किया गया है।

ABSTRACT. In developing countries like India, the urban environment is constantly under stress as a result of migrant population, enhanced energy consumption of the growing population, increased traffic load and industrial activity, deforestation and release of waste products into the atmosphere and hydrosphere. This urbanization coupled with industrialisation affect the urban climate like temperature, precipitation, wind, relative humidity and bright hours of sunshine. Most of the studies are mainly confined to the mid-latitude cities and very little is known about these urban induced changes (except for temperatures) for low latitude cities.

There has been a conspicuous increase in the number of industries after 1950 in the cities. Fifteen cities (including four metros) with a population of more than 1 million are selected for this study. Linear trend analysis was carried out over the climatologically data for different meteorological parameters *viz*., incoming solar radiation, bright hours of sunshine, relative humidity, rainfall, wind speed, total cloud amount and maximum and minimum temperatures. The trends observed in these meteorological parameters are discussed.

Key words – Urbanization, Clouds, Relative humidity, Solar radiation, Rainfall, Sunshine, Wind, Trends, Heat wave.

1. Introduction

Urban populations are growing very rapidly throughout the world. Besides this, the world population is urbanizing much faster than is growing. Phenomenal population growth coupled with fast pace of industrialization have been responsible for urban environmental hazards. In the beginning of the 20th century, India had only one city with more than 1 million population while the number of such cities are now more than twenty. At present more than 218 million people live in the cities in India, which is second largest in the world.

Industries, automobiles, domestic fuel consumption and the use of domestic appliances contribute to the emissions while gases from garbage dumps add to the deterioration of the air quality and warming of the city

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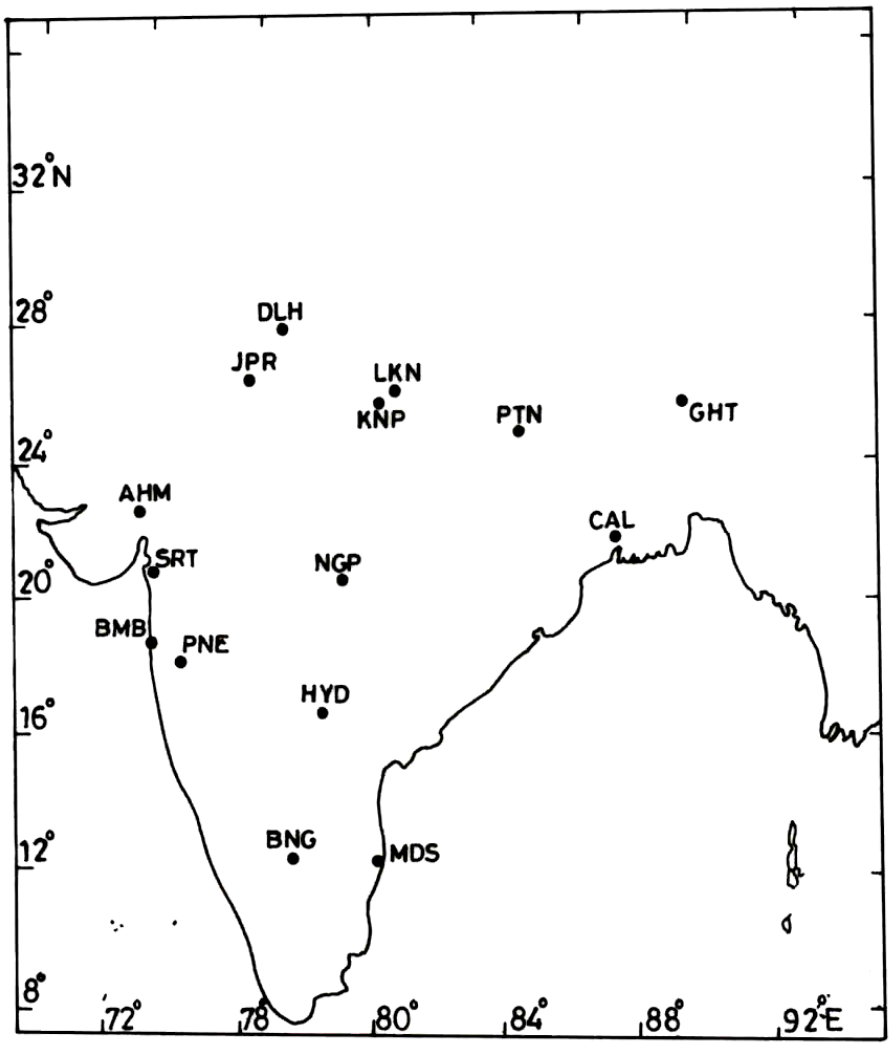

Fig. 1. Location of fifteen cities

environment. During the quarter century between 1971 to 1995, the number of automobiles increased 16 times for a population increase of about 1.6 times (Statistical Abstract of India 1998 and Malayalam Manorama 1998). Most meteorological parameters are affected by urbanization. Though the work on climates of tropical cities started a few decades ago, the available information is extremely sparse except for temperatures. Lot of work is done on surface air temperature by various authors (Hingane *et al*. 1985, Rupakumar and Hingane, 1988, Sen Roy and Prasad, 1991, Srivastava *et al*. 1992) and concluded that there is a warming trend in all India surface air temperature. Studies in the mid latitudes established beyond doubt that urban agglomeration cause measurable changes in the atmosphere immediately adjacent to them *e.g*., temperatures are increased, horizontal winds slowed, summer rainfall is enhanced. The increases in atmospheric pollutants reduce solar radiation intensity, affect long wave radiation and shorten sunshine duration.

To study the effect of urbanization on the above meteorological parameters, fifteen Indian cities (including four metros), with a population of more than 1 million are selected and shown in Fig. 1.

2. Data and methodology

Meteorological data pertaining to the Indian region were collected from India Meteorological Department (IMD) at Pune. The linear trend analysis was carried out for monthly mean meteorological parameters and the

TABLE 1

Trends of annual means of radiation, sunshine duration, relative humidity, total annual rainfall, wind speed, total cloud amount and percentage frequencies of summer maximum temperature > 35° C and winter minimum temperature < 10° C

S. No.	Station Name	Radiation	Sun-shine	Relative humidity	Rainfall	Wind speed	Total cloud amount	(%) Frequency of temperature	
								Maximum >35° C	Minimum <10° C
1.	New Delhi	– #	– #	+ #	+ #	– #	–	–	–
2.	Jaipur	–	+ #	+ #	+	– #	–	–	– #
3.	Kanpur	*	–	+	–	– #	–	– #	+
4.	Lucknow	*	– #	+ #	–	– #	+	+	–
5.	Guwahati	*	– #	+ #	+ #	– #	+	–	– #
6.	Patna	–	– #	+ #	–	– #	–	–	–
7.	Ahmedabad	– #	–	+ #	+	– #	–	+	–
8.	Kolkata	– #	– #	– #	+ #	– #	+	+	– #
9.	Surat	*	+	+ #	+	–	– #	+	– #
10.	Nagpur	– #	–	+ #	–	– #	– #	–	– #
11.	Mumbai	– #	– #	+ #	+ #	– #	– #	+ #	+
12.	Pune	– #	–	+ #	+ #	+ #	+ #	– #	–
13.	Hyderabad	+ #	– #	–	+	– #	– #	+	– #
14.	Chennai	– #	– #	– #	+	– #	–	+ #	**
15.	Bangalore	+	– #	+ #	+ #	– #	– #	+	**

* : Data not available, # : Trend is significant at 95% confidence level , + : Trends are increasing , ** : Minimum temperature <10° C was not reported, – : Trends are decreasing

TABLE 2

Period of data considered and percentage change for each parameter

Station	Radiation		Sunshine		Relative humidity		Rainfall		Wind speed		Total cloud amount	
	Period	% increase / decrease (-)	Period	% increase / decrease (-)	Period	% increase / decrease (-)	Period	% increase / decrease (-)	Period	% increase / decrease (-)	Period	% increase / decrease (-)
New Delhi	1957-2000	-5	1957-2000	-22	1901-2001	14	1901-2000	33	1952-2001	-54	1951-2001	-1
Jaipur	1985-1999	-1	1969-1999	7	1952-2000	7	1901-2000	10	1952-2000	-36	1952-2000	-1
Kanpur	@		1964-1975	-3	1901-1991	1	1901-1991	-3	1952-1991	-34	1951-1991	-5
Lucknow	@		1962-1996	-8	1952-2000	12	1901-2000	-7	1952-2000	-37	1952-2000	6
Guwahati	@		1969-1998	-19	1951-2001	2	1902-1998	12	1951-2001	-20	1951-2001	3
Patna	1985-1999	-5	1960-2000	-17	1951-2000	12	1901-2000	-3	1951-2000	-38	1951-2000	-3
Ahmedabad	1962-2000	-8	1962-2000	-2	1901-2000	21	1901-2000	3	1952-2000	-37	1951-2000	-4
Kolkata	1957-2000	-11	1957-1999	-20	1901-1999	-16	1901-1999	18	1951-1999	-37	1951-1999	4
Surat	@		1950-1989	1	1901-2000	5	1901-2000	3	1952-2000	-3	1951-2000	-17
Nagpur	1960-2000	-6	1960-1998	-2	1901-1998	7	1901-1995	-13	1951-1998	-23	1951-1998	-8
Mumbai	1969-2000	-5	1969-2000	-8	1901-2000	4	1901-2000	30	1952-2000	-59	1951-2000	-7
Pune	1957-2000	-4	1945-2000	-3	1901-2002	15	1901-2000	23	1952-2002	38	1951-2002	14
Hyderabad	1978-1999	21	1969-1998	-8	1951-1998	-1	1901-1998	9	1951-1998	-13	1951-1998	-11
Chennai	1957-2000	-5	1957-1999	-4	1901-1999	-5	1901-1999	5	1951-1999	-30	1951-1999	0
Bangalore	1981-1998	2	1953-2000	-24	1901-2000	4	1901-2000	17	1951-2000	-58	1951-2000	-8

@ : Stations are not recording radiation measurements

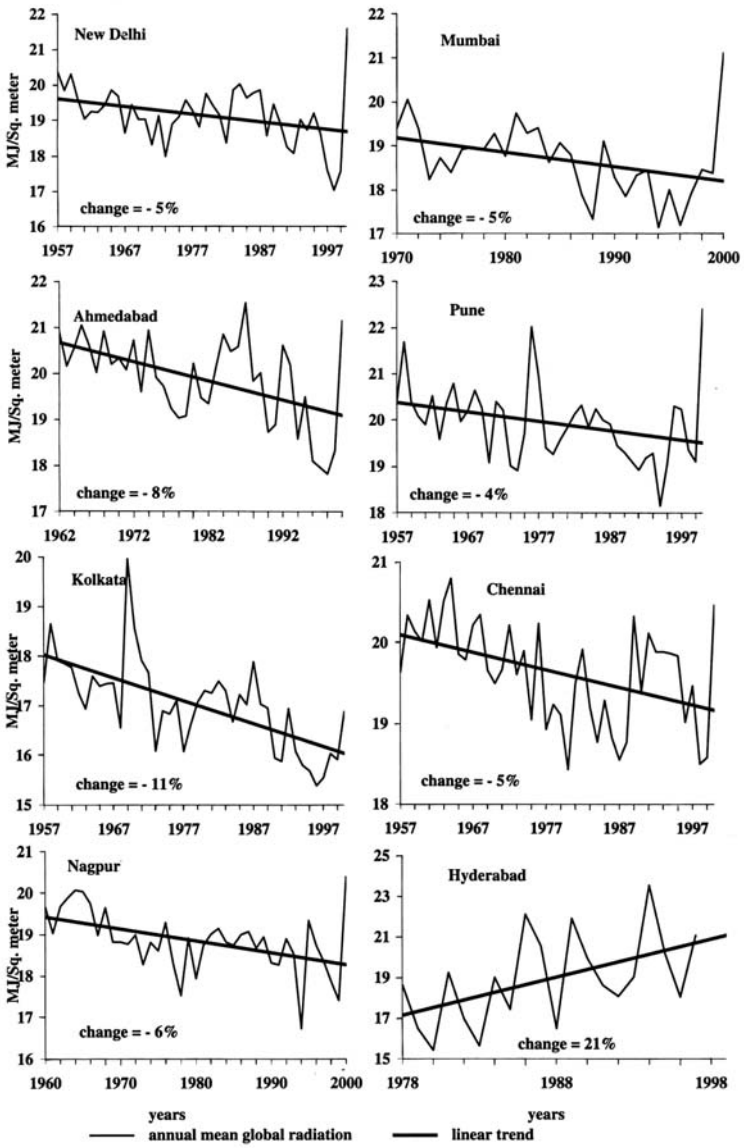

Fig. 2. Annual mean global radiations significant at 95% level

significance was tested at 95% level of confidence by using *t*–statistic. The trends (positive or negative) exhibited by different stations on individual parameters are given in Table 1 while the percentage change of the parameter calculated for the availability of the data period are presented in Table 2.

3. Discussions

3.1. *Impact of Urbanisation of meteorological parameters*

3.1.1. *Total incoming short wave radiation*

The urban areas are now in the process of increasing their industrial production and little control has been exerted to reduce emissions of gases and particulates. Consequently, the increasing amounts of pollutants in tropical urban areas lead to greater absorption, scattering and reflection of incoming solar radiation, which in turn reduces the amount of energy reaching the urban surface.

The radiation data were analysed for available 11 stations except Kanpur, Lucknow, Guwahati and Surat. Results indicate that New Delhi, Ahmedabad, Kolkata, Nagpur, Mumbai, Pune and Chennai are showing significant negative trends (Fig. 2). The percentage decrease varies from station to station between 11% at Kolkata to 1% at Jaipur. Hyderabad and Bangalore exhibit increasing trends, though they were significant for Hyderabad only. The increase in total incoming solar

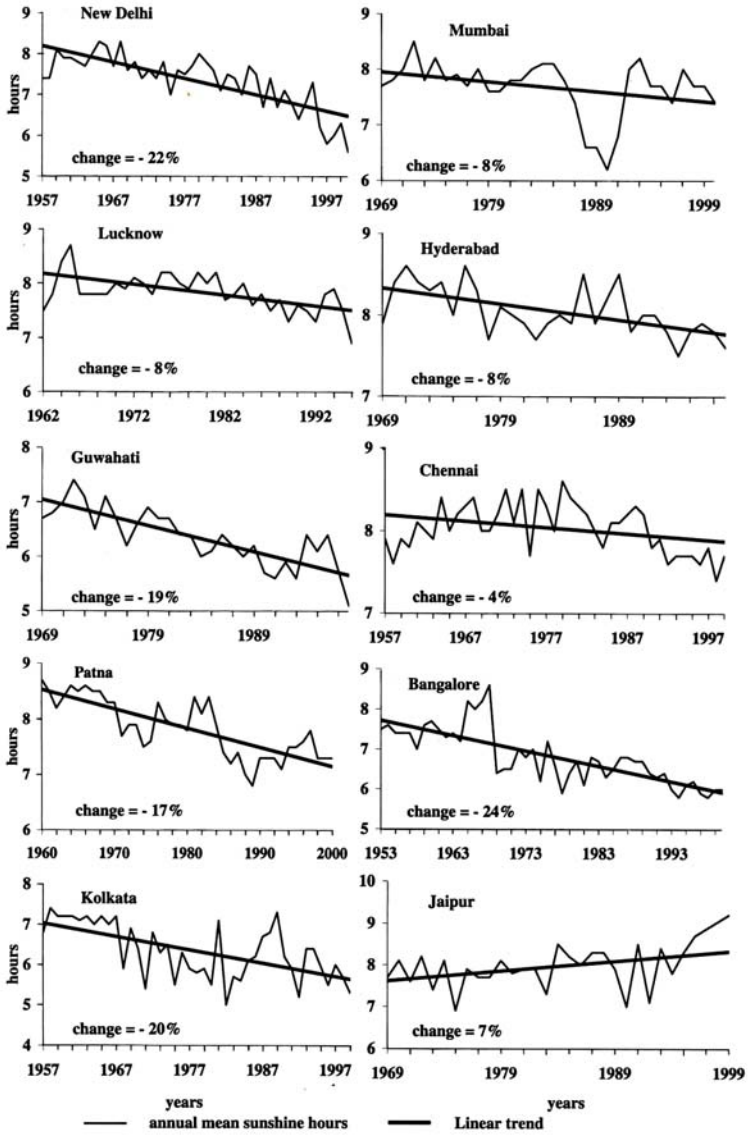

Fig. 3. Annual mean hours of sunshine significant at 95% level

radiation was found 21% for Hyderabad and 2% for Bangalore.

3.1.2. *Sunshine*

The emissions from small vehicles, heavy diesel trucks, burning of trees and smoke from stoves that burn wood and tiny suspended particles in the atmosphere called aerosols form a sheet of varying thickness causing lack of transparency in the air. This cuts the amount of sunlight reaching the ground with adverse effects.

The numbers of bright hours of sunshine are decreasing for thirteen stations except Jaipur and Surat. The decreasing trend is significant for nine stations except Kanpur, Ahmedabad, Nagpur and Pune (Fig. 3). The maximum decrease in annual mean sunshine hours is 24% for Bangalore while Nagpur and Ahmedabad are having lowest value (2%).

3.1.3. *Relative humidity*

Little information is available in the literature on humidity effects. In mid-latitudes, the relative humidities

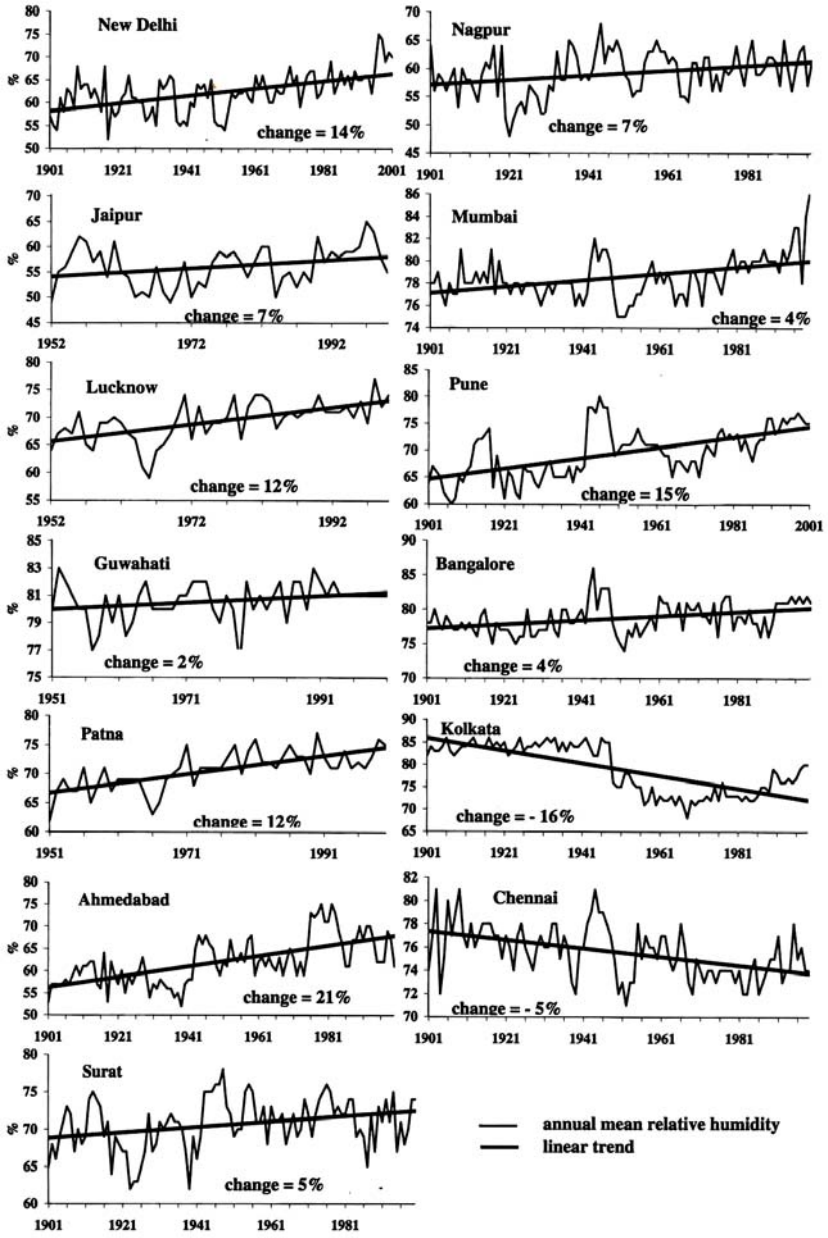

Fig. 4. Annual mean relative humidity significant at 95% level

are lower in the urban areas because of the heat island effect. But in the present study, this effect is not seen at all the stations. The relative humidity values are having increasing trend for 12 stations and significant for 11. The maximum increase in annual mean relative humidity is for Ahmedabad (21%) and the minimum increase is for Kanpur (1%). Kolkata, Hyderabad and Chennai exhibit a decreasing trend, which is significant for Kolkata and Chennai. The significant trends are given in Fig. 4. The variation in the decreasing trend is in the range of 16% (Kolkata) to 1% (Hyderabad). The heat island effect may cause lower humidities but one has to study the flow rate of diffusion air, density of population and tall buildings effect before generalization.

3.1.4. *Rainfall*

Urbanization leads to increased buoyancy and convection thereby resulting in increased precipitation (Padmanabhamurty and Bahal 1984). Eleven stations are

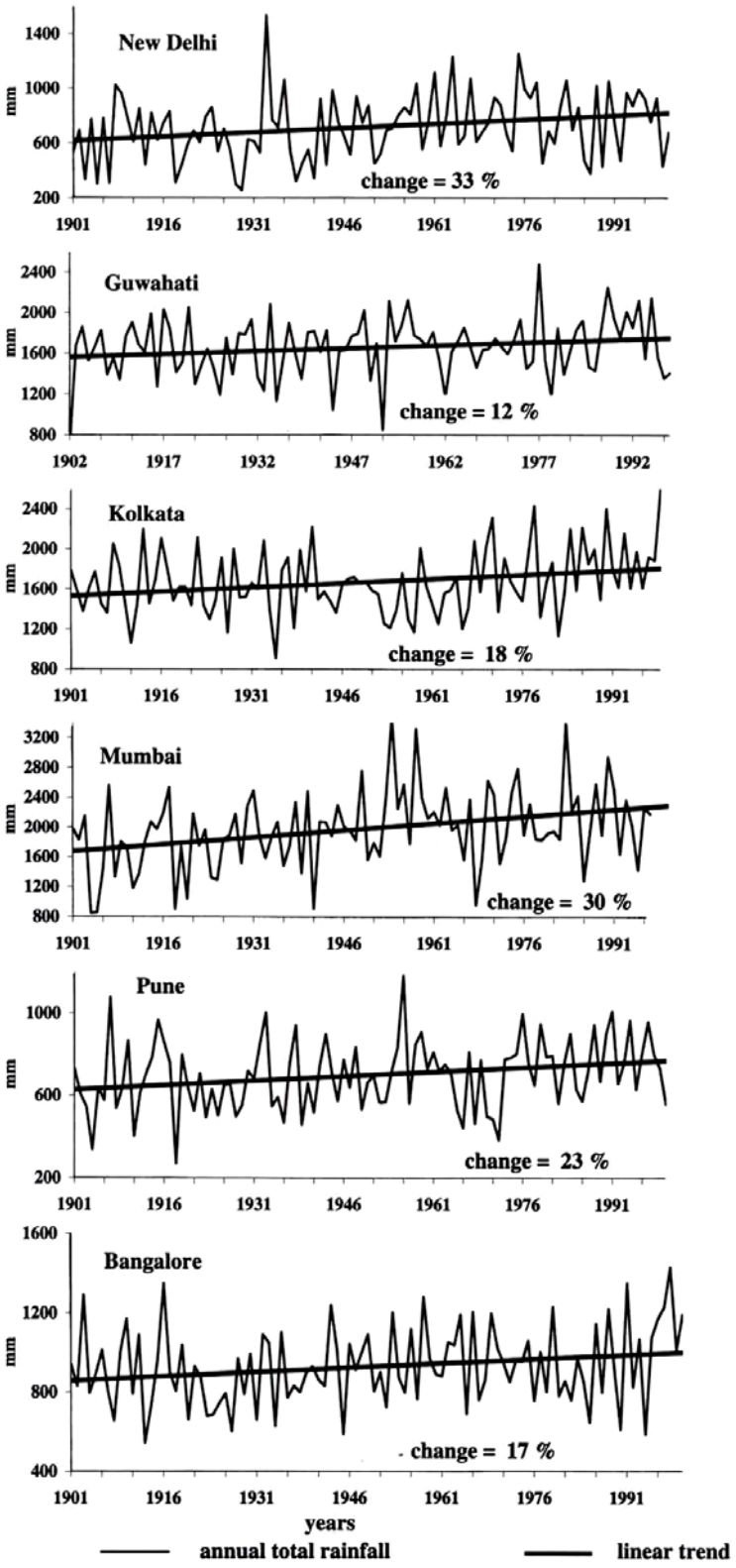

Fig. 5. Annual rainfall trends significant at 95% level

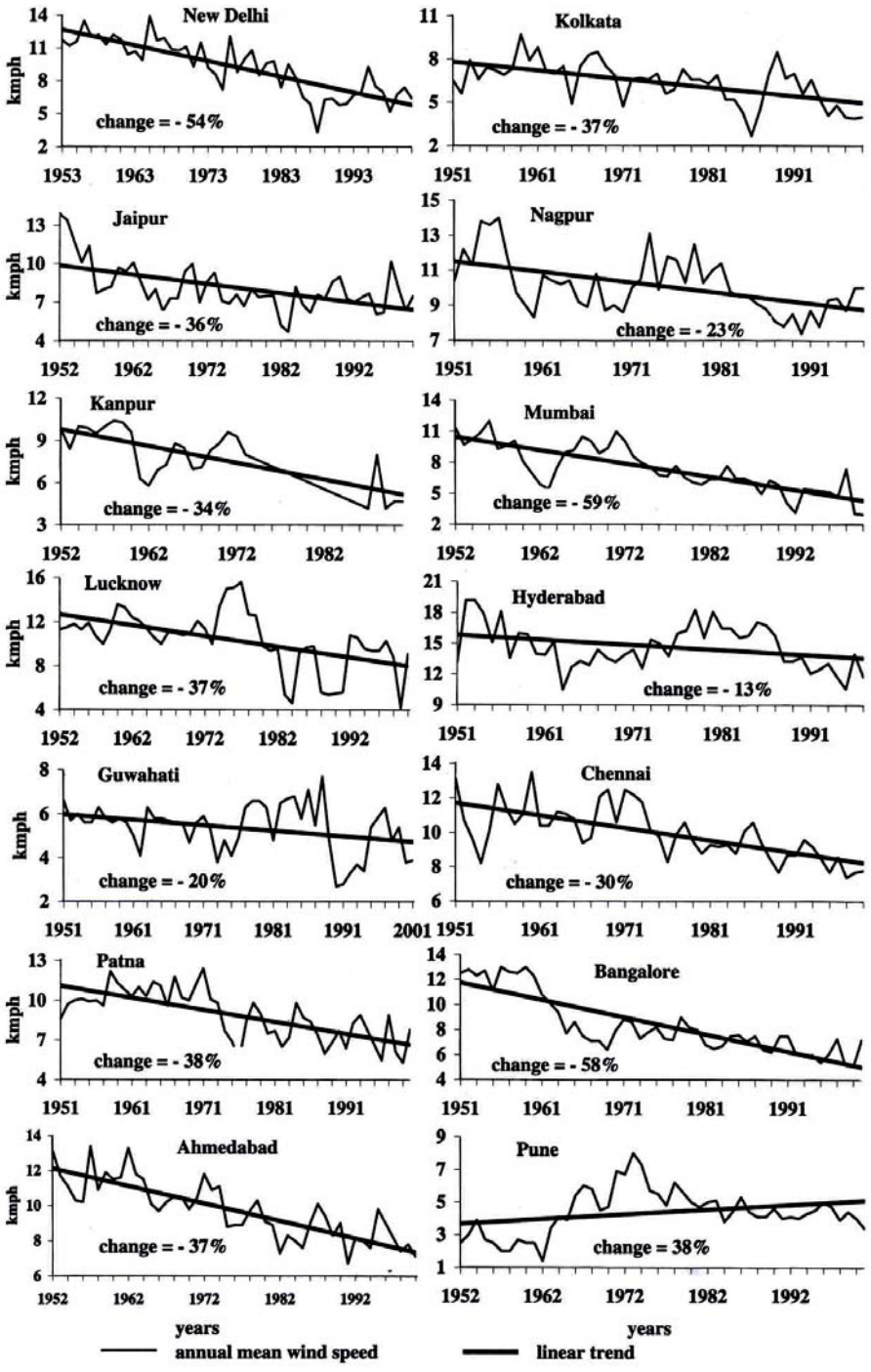

Fig. 6. Annual mean wind speed significant at 95% level

showing increasing trend in annual rainfall in conformity with urbanisation effect and significant for New Delhi, Guwahati, Kolkata, Mumbai, Pune and Bangalore (Fig. 5). The increase in annual total rainfall varies between 33% at New Delhi and 3% at Ahmedabad and Surat. However, rainfall trends at Kanpur, Lucknow, Patna and Nagpur are

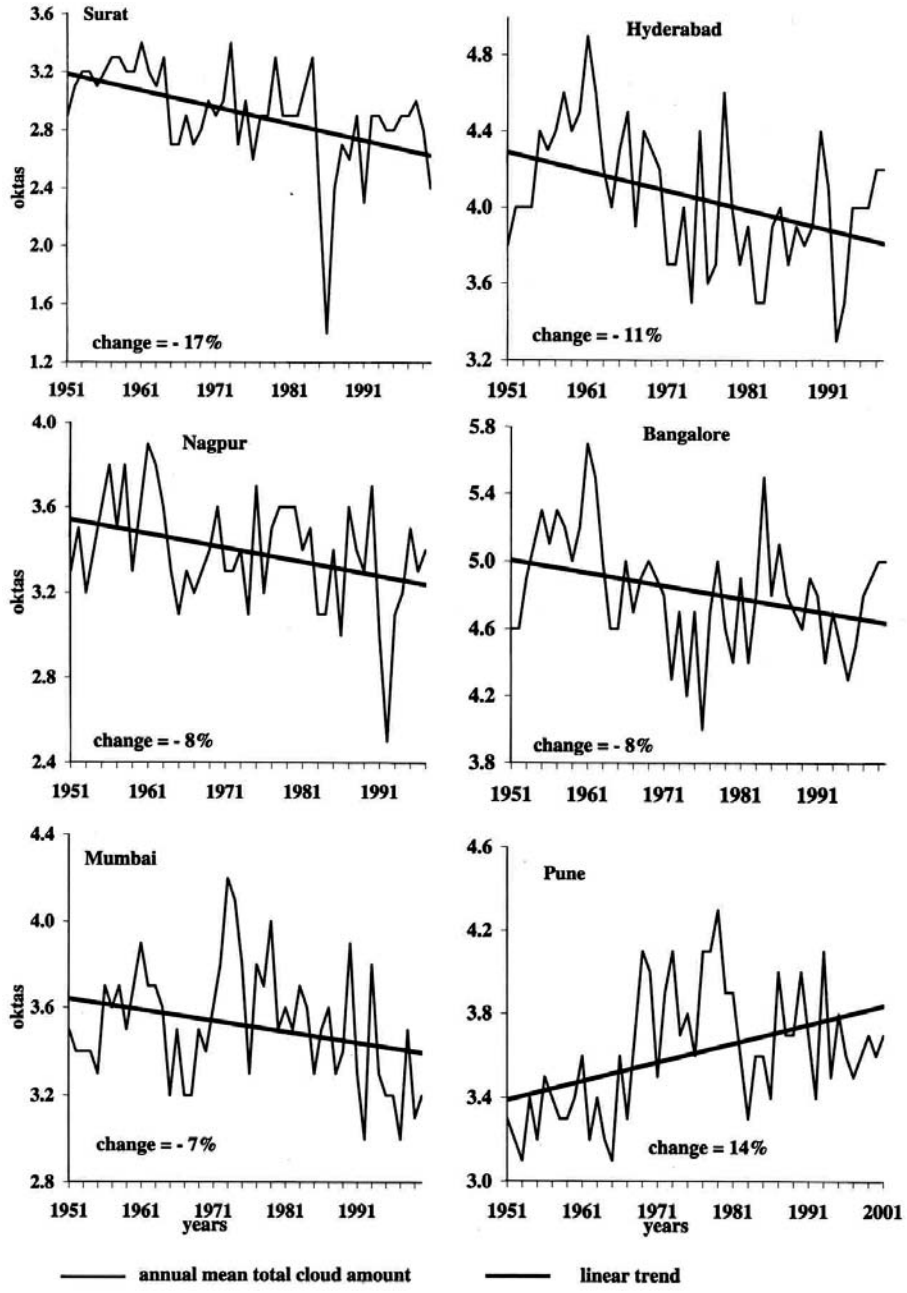

Fig. 7. Annual mean total cloud amount trends significant at 95% level

decreasing but are not significant. This decrease in annual total rainfall varies between 13% (Nagpur) and 3% (Kanpur, Patna).

Reports in the literature are divergent on the effects of urbanization and industrialization on precipitation. Arguments are advanced that, large city with a super abundance of condensation nuclei, influence precipitation processes towards a reduction in precipitation by increasing the number of small droplets in the form of clouds and smog. On the other hand smaller urban complexes may supply the right amount of additional condensation nuclei to increase precipitation amounts. Further studies are necessary in this direction.

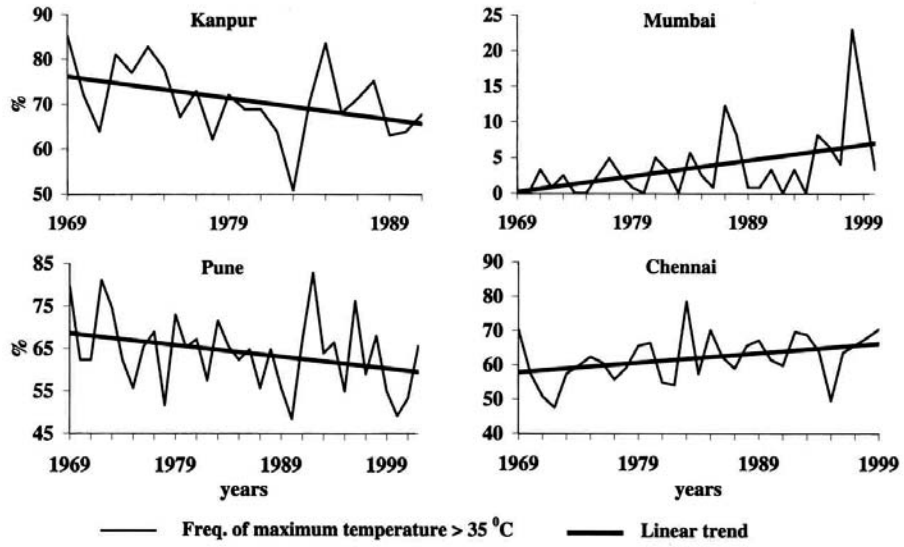

Fig. 8. Percentage frequencies of maximum temperature >35° C during March to June significant at 95 % level

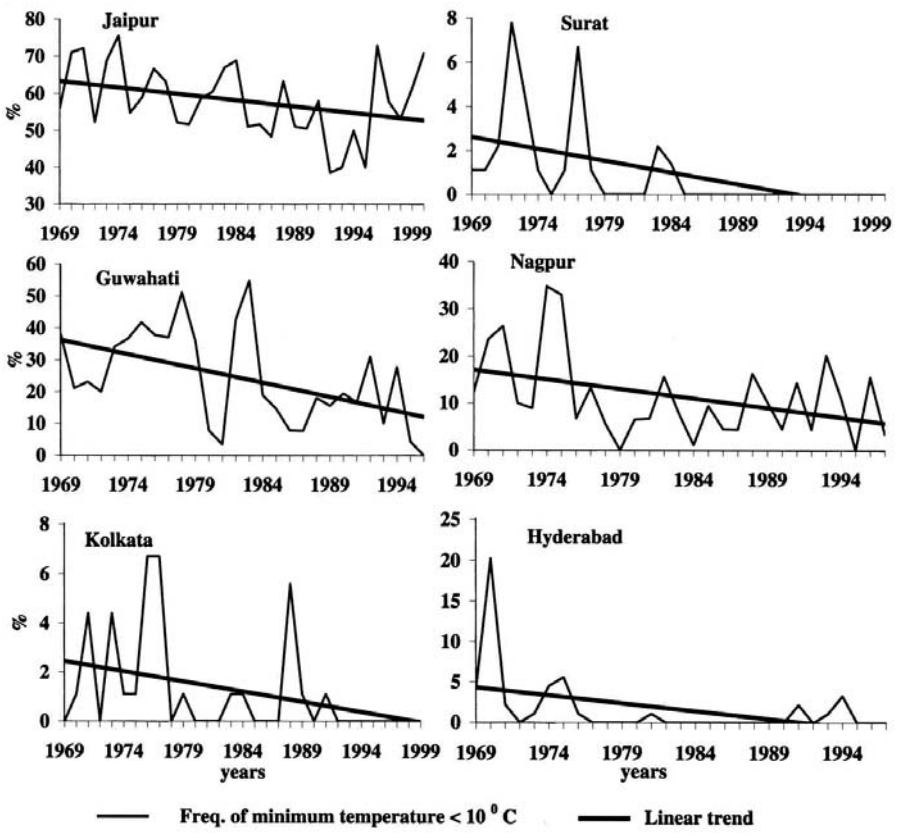

Fig. 9. Percentage frequencies of minimum temperature <10° C during December, January and February significant at 95 % level

3.1.5. *Wind speed*

Landsberg (1970) has pointed out that in the large industrial cities, wind speeds are reduced by 25% and the frequency of calms is increased by 5-20%. The increase in surface roughness within cities causes a reduction of strong wind speeds during the day.

Except Pune (+38%), all the remaining 14 stations showed a decreasing trend during the daytime. The decreasing trends are significant for 13 stations except Surat (Fig. 6). The reduction in wind speed varies between 59% (Mumbai) and 3% (Surat).

3.1.6. *Total cloud amount*

The measurement of total cloud amount is subjective and proper care has to be exercised while inferring. The total cloud amount trends are decreasing in respect of 11 stations out of which for 5 stations (Surat, Nagpur, Mumbai, Hyderabad and Bangalore), the trends are significant. The percentage decrease varies from 1% (New Delhi and Jaipur) to 17% (Surat). Lucknow, Guwahati, Kolkata and Pune are having increasing trends in cloud amounts, however trend only at Pune is significant (Fig. 7). The increase in annual mean total cloud amount varies between 3% (Guwahati) and 6% (Lucknow).

3.1.7. *Temperatures*

In the present study the percentage frequency of the number of days with summer maximum temperature more than 35^{o} C and winter minimum temperature less than 10^{o} C were studied as they have more effects on human beings. The trends for maximum temperature are decreasing for New Delhi, Jaipur, Kanpur, Guwahati, Patna, Nagpur, Pune and significant for Kanpur and Pune only. The trends are positive over Lucknow, Ahmedabad, Kolkata, Surat, Mumbai, Hyderabad, Chennai, and Bangalore and are significant for Mumbai and Chennai (Fig. 8).

The minimum temperature trends are negative for New Delhi, Jaipur, Lucknow, Guwahati, Patna, Ahmedabad, Kolkata, Surat, Nagpur, Pune and Hyderabad and are significant except for New Delhi, Lucknow, Patna, Ahmedabad and Pune (Fig. 9).

3.2. *Future projections*

Over next 30 years, global population is projected to grow by nearly $2/3^{rd}$ from current 5.5 billion to 8.5 billion. About 7.1 billion people will live in developing countries alone. Population in industrialised countries is now 1.2 billion, which is projected to rise 1.4 billion by the year 2025. World population is urbanising due to shrinking economic opportunities in rural areas. This trend is going to increase the population of mega cities, which are sources of environmental hazards. Disposal of human and industrial waste in rivers and air not only affect the atmosphere and climate but also degrade the quality of fresh water. Rain brings about 400 million hectare meters of water each year to India. However, seventy percent of India's water supply is polluted. It is time for the policy makers to do something.

4. Conclusions

(*i*) The trends shown by the various meteorological parameters are not uniform for all the Indian cities.

(*ii*) In general radiation values, bright sunshine hours, wind speeds and total cloud amounts are decreasing. Relative humidity, rainfall amounts are increasing. Percentage number of days of maximum/minimum temperatures with a threshold value of >35° C / <10° C are decreasing / increasing respectively over north India while maximum temperature days are increasing over south India.

(*iii*) Orography, the density of population, the distance between the tall buildings, vehicular pollution and the industrial development play an important role in controlling the urban climate.

(*iv*) At this present stage of development, urban climate studies based on routine climatological data leading to description of meteorological features will be necessary for some more time in tropical areas until sufficient knowledge is available for generalisation.

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